SEAL DURABILITY IN INSULATING GLASS UNITS: SUMMARY OF TECHNICAL ISSUES AND RECOMMENDATIONS TO THE DEPARTMENT OF ENERGY

A. W. Czanderna, NREL Consultant's Report to R. Anderson and J. R. Pitts
National Renewable Energy Laboratory (NREL), Golden, CO 80401-3393

Executive Summary

The technical issues about the durability of seals in insulating glass units (IGUs) are discussed and are used as a basis for making recommendations for potential involvement by the Department of Energy. The content of this report is based on discussions with 13 experts in the field of IGU seal durability and performance. The principal degradation mechanisms of seal failures are loss of adhesion between the sealant material and the glass or spacer or rapid permeation of gases through the sealant material (s). The causes of failure generally result from a poor choice of materials, careless manufacturing practices, poor installation practices, or details of the IGU design when exposed to a service environment of solar irradiation, temperature extremes, and water or water vapor. In general, failures are gradual rather than catastrophic. ASTM Standards, which were adopted in the 1970s and 1980s for accelerated life testing (ALT) of IGUs, have permitted establishing a fair to excellent relationship with the service life of IGUs in actual service environments. A good correlation with lifetime and ALT was obtained from studies by the sealed insulating glass manufacturers association (SIGMA) from 1980 to 1995. Service lifetime estimates by some individual manufacturers, which are rarely made by most manufacturers, have been based on ALT and more than 20 years of real-time data and the ALT of comparable units. The ASTM test (E 773-97 and the companion specification E 774-97) for ALT IGUs is known as the P-2 test in industry; it was chosen over a P-1 test in the 1970s. The differences between these tests and their historical development are discussed briefly and proposed ASTM standards in the 1970s are included as Appendices. Some industries use P-1 and P-2 for testing new materials and designs and estimating their projected lifetimes. No protocol has been studied for making a service lifetime prediction of new or modified IGU designs with relatively short real-time exposures to in service conditions.

The use of argon in an IGU as an energy-saving benefit when coupled with the known failure mechanisms is seriously questioned, especially when compared with the energy saving benefit and simpler manufacture of an air-filled double glazed system with low E coatings. Because of differential permeation rates among argon, nitrogen, and oxygen, contemporary argon-filled IGUs may experience an increase in the U-factor for two reasons. The first reason results from the replacement of argon inside the IGU with the better-conducting air and the second reason is from the change in shape of the glass from the pressure differential between the outside air and inside volume of the IGU. One manufacturer, which uses a thermoset polymer instead of a metal for the spacer between the two glass panes and an inverted dual seal design, claims they have essentially mitigated the causes of seal degradation. The potential need for portable units for measuring the gas content of IGUs deployed in the field and during IGU production is discussed. Although vast amounts of knowledge and understanding of IGU seal durability are known by technical people in industry, unbiased peer-reviewed summaries are rare about the status of the technical issues, especially related to the durability of IGU seals. A simple brochure for consumers on how to select an energy efficient fenestration product at an optimum price is a

recognized need. A summary of recommendations for future involvement of the Department of Energy for helping industry and the consumer is given.

Introduction

At the suggestion of R. Anderson and G. Jorgensen of NREL, the author agreed to prepare this report about the technical issues and to make recommendations about the appropriate role for the Department of Energy related to insulating glass unit (IGU) seal durability. From his past activities with NFRC and ASTM Task Group E06.22.05, the author identified 14 known experts in the field of IGU seal durability and carried out telephone conversations with 13 of them that ranged from 30 to 180 minutes in length. Prior to any conversation, each person contacted was sent the list of 13 questions and comments given in Appendix 1. The format of this report is structured around these questions and comments. Additional clarifications were asked of R. Spindler about the presentation he gave at a meeting held by the Sealed Insulating Glass Manufacturing Association (SIGMA) in 1999 (Appendix 2); his responses are included in the text as appropriate.

The need for this report was prompted in part from a recent legal case against the Hurd Corporation (Appendix 3). More importantly, Dr. Sam Taylor raised concerns that (1) seal failures on contemporary IGUs may be resulting in less energy savings than without the seal failures and (2) DOE should appropriately anticipate the need for a well-established durability (predicted service lifetime is a better term) of seals in IGUs before advanced windows, e.g., IGU units with electrochromic (EC) coatings on the inside of at least double pane units, are sold to consumers. EC coated IGUs are already being subjected to accelerated life testing at NREL to assess the durability of the EC coatings. Some EC coatings are known to be reactive with water vapor, so the service lifetime of an EC coating is closely intertwined with the service lifetime of the sealant system in the IGU.

IGU Experts Contacted

The following experts on IGU seal durability were contacted by the author by sending an email (Appendix 1) and then by telephone.

Dariush Arasteh, LBNL, Berkeley, CA
Chris J. Barry, Technical Manager of Architectural Products, LOF Co., Toledo, OH
James C. Benney, NFRC Staff, (formerly of PGMC), Berryton, KS
Hakim Elmahdy, National Research Council, Ottawa, Ontario, Canada
James Fairman, Aspen Research Corporation, White Bear Lake, MN
Jeffrey E. Haberer, Cardinal IG, Minneapolis, MN
David Kehrli, ETC Laboratories, Rochester, NY
Werner Lichtenberger, TruSeal Technologies, Ltd., Hamilton, Ontario, Canada
William Lingnell, Lingnell Consulting Services, Rockwall, TX
Allan Major, Bodycote Ortech, Inc., Mississauga, Ontario, Canada
Gerhard Reichert, Edgetech IG, Inc., Cambridge, OH
Robert G. Spindler, Cardinal IG, Minneapolis, MN
Mark C. Sullivan, AFG Industries, Inc., Kingsport, TN

Summary of Recommendations

Each recommendation given in this summary is based on input obtained during telephone and personal conversations with the participants. Except for the first recommendation, they are not ordered in their rank of importance but are generally listed in the same sequence as they appear from responses to the questions and comments (Appendix 1). It is recommended that the Department of Energy

A. Fund and convene a panel of five to nine experts on IGU seal durability to discuss the recommendations of this report, to identify any other potential needs, and to develop a prioritized list of recommendations for support by DOE as permitted by available funding. Consider the following individuals for serving on the panel: R. Spindler, J. Fairman, W. Lichtenberger or J. Baratuci, C. Barry, M. Sullivan, R. Ernst, W. Lingnell, C. Wagus, and a representative of NREL, e.g., A. Czanderna or G. Jorgensen.

B. Fund NREL (1) to develop new accelerated testing protocols for IGUs that result in failures that can be correlated with failures encountered from in-service use, (2) to purchase two chambers for evaluating the merits of P-1 and P-2 testing [see Section 2 (a)] and the newly devised protocols, and (3) to lead a task for consolidating all the variations in accelerated and real time testing into one protocol and have it balloted to be an ASTM standard.

C. Fund NREL and other independent laboratories with in-depth experience with IGU testing to assess the durability of IGUs, develop a plan for predicting service lifetimes, and implement the plan.

D. Lead aggressively through standards organizations for adopting standard procedures, practices, methods and specifications many years before new advanced window technologies are ready for the consumer.

E. Evaluate the energy-saved versus consumer cost when using argon instead of air in an IGU.

F. Fund the deployment of a portable spectrometer or suitable variants, e.g., the Elmahdy device, for the non-destructive, non-invasive determination of the concentration of argon or krypton in field- or laboratory tested IGUs. Alternatively, fund the development of a different type of portable spectrometer or suitable variants, e.g., one that is based on spectroscopic analysis such as used by Cardinal IG. A unit is needed to monitor the percentage of inert gas fill for production lines.

G. Obtain the water permeation rates for commonly used seal materials.

H. Fund a scholarly person to work with selected individuals in industry to prepare summaries of the knowledge available about IGU durability and publish these in peer-reviewed journals, e.g., convert R. Spindler's SIGMA paper (Appendix 2) into an ASHRAE paper.

I. Produce simplified brochures for the consumer on "how to select an energy efficient window for his/her home" perhaps, by working through NFRC.

J. Use a model and computer simulation to estimate the effect of gap collapse on the increase in U-factors from temperature-induced pressure changes as well as those resulting from the pressure decrease because of the net loss of molecules inside the IGU from out-diffusion of argon (Aspen Research has not published their calculations on the effects of gap collapse).

K. Consider the other recommendations summarized in response to question 13(c).

L. Address the quality management or control of actual manufacturing processes and assess to what extent, if any, DOE should become involved. Quality control during the manufacturing of IGUs is a significant worldwide issue.

M. Evaluate a unique, non-conventional reverse dual seal design that greatly reduces the durability issues compared with the conventional seal design used by most IGU manufacturers and compare the predicted service lifetimes of the two types of designs.

Responses to Questions and Comments About Seal Durability in IGUs

1(a). What is the current understanding of degradation mechanisms of seals?

Please view page 31 of Appendix 2 for a cross sectional view of a dual seal design. Loss of adhesion between the sealant and glass or spacer (a large percentage of all failures) results from an improper choice of materials (e.g., a sealant that becomes embrittled or is incompletely cured or outgassed), UV irradiation-induced degradation of the polymeric seals, defects during manufacturing such as fingerprints or other poor workmanship, contamination of the spacer or glass surfaces from other sources such as incomplete washing of detergents, water or water vapor that enters the IG space (e.g., water collects at the bottom if weep holes are not present and freeze-thaw induces stresses), charging the unit with a loaded desiccant, and oxidation of the sealant. The key stress parameters are water vapor or liquid water, temperature, and UV from solar irradiance. Most participants cited insufficiently cleaned surfaces and careless practices during manufacturing as sources of contaminants that may induce degradation.

In the imperfect world of manufacturing, "skips" can result when applying the primary seal, e.g., polyisobutylene (PIB). The skip is a break in the continuity of the primary seal that results in much more rapid permeation of gases through the secondary seal. Rapid permeation of gases through the secondary seal results in a minor failure in the unit in which the inert gas is replaced with air. The exchange of gas not only results in increases in the U-factor from the change in the conductivity of the gas but also dishing or collapse of the glass (see question 6 for more detail). Then a permanent failure can occur because the desiccant becomes filled to capacity with water vapor and the dewpoint rises to a temperature greater than –40°C. Failures from permeation may also result from selecting the wrong sealant or using the wrong sealant components during application. Without skips in the primary seal, IGUs ultimately fail from desiccant saturation.

Edgetech has greatly mitigated the degradation problems by using a unique ***reverse*** dual seal design from that shown on p. 31 of Appendix 2. Their designers have placed the structurally supportive secondary seal *inside* the IGU, used a thermoset polymer spacer that is held in place by a desiccant containing 3-M type double sided tape to separate the glass panes, and placed the primary seal (a hot butyl melt is the moisture barrier) on the outside of the of the spacer. The thermoset polymer remains rubbery for the temperature range experienced by IGUs and mitigates the differential expansion mismatches and de-adhesion problems encountered when using metal spacers. The reverse dual seal design has a failure rate of less than 0.01% compared with 0.1% for the lowest failure rate with the conventional spacer design and construction and with 4% obtained from the SIGMA study of IGUs, all made with the conventional spacer design. IGUs with the reverse dual seal design, which have only a small market penetration, are thought by some people to be the choice design for the future.

Recommendation: Evaluate a unique, non-conventional reverse dual seal design that greatly reduces the durability issues in the conventional seal design used by most IGU manufacturers and compare the predicted service lifetimes of the two types of designs.

1(b). Are the causes of ruptured seals, bond loss (de-adhesion), and permeation failures known?

Yes. They are included in the degradation mechanisms given in 1(a). Ruptured seals generally occur in cases where the IGU experiences severe pressure differentials. Ruptured seals may result from stresses on the sealant during manufacture (not properly supported) or from the pressure changes inside the deployed unit from cold winter days or hot summer days. PIB is a thermoplastic and can change shape to accommodate the temperature-induced stresses, but other sealants are thermosets and can rupture from stresses, if the thermoset is not properly chosed. By using the methods and practices for testing IGUs described in ASTM standards (Appendix 4), many of the degradation mechanisms have been identified.

1(c). Are there any other failure modes?

Glass breakage may occur, e.g., through poor glass cutting techniques, spacers may cause stresses and breakage, and spacer bars may shift during manufacture. Corrosion of the "soft" Lo-E coats, i.e., silver films, may result from water vapor transporting reactants such as chlorides and sulfides to the silver surface. The result is an increase in the U-factor.

1(d). Are failures always, usually, or rarely catastrophic?

Except for the cases involving rupture, they are rarely catastrophic. The effectiveness of the seal gradually degrades with time with concomitant slow changes in the performance parameters.

2(a). What are the accelerated testing procedures used to assess the durability of seals?

The existing ASTM standards, proposed ASTM standards, the existing Canadian Standards, and the proposed CEN (Comité Européen de Normalization in Europe) standards are listed in Table 1. In the United States, ASTM E 773-97 (Appendix 4) is ***the*** accepted accelerated testing method and the results are evaluated according to the ASTM standard specification E 774-97 (Appendix 4). In Canada, the accepted testing method is CAN/CGSB 12.8. In North America, a consolidation of the ASTM and Canadian Standards is underway; the three proposed ASTM standards (E-XXX, E-YYY, and E-ZZZ) as of August 2000 are also collected in Appendix 4. Revised versions of the proposed standards will be balloted in early 2001. In Europe, a number of testing procedures are being consolidated by representatives from the member countries of the CEN [1]. The CEN standards are also at an advanced stage of development.

The procedure described in ASTM E 773-97 is known as P-2 testing and is ***the*** accepted standard, but a number of IG manufacturers use a "P-1" test, which most think is a harsher test. In P-1 testing, the IG unit is subjected to 100% R.H. at 140°F with continuous exposure to UV lamps. Only two UV lamps are used in the P-2 test whereas many more lamps are used in the P-1 test. The standard specification is known as P-3, and ASTM E774-97 is ***the*** accepted standard. The accepted standards emerged from balloting in ASTM in the 1970s and historically important documents are collected in Appendix 5. The first three documents are the 1970s versions of P-1, P-2, and P-3. The remaining documents in Appendix 5 are concerned with the amount of UV exposure that reaches the sealant material, and the years of equivalent UV exposures in each of the two tests (P-1, 300 y and P-2, 100 y). The additional lamps used in P-1 testing not only increases the irradiance of UV incident on the polymeric sealant materials, but also assures that the sealant material is irradiated. P-1 chambers are available from Alpine Heating and Air Conditioning, 34600 Lakeland Blvd., East Lake, OH 44095 (440-942-1562).

Most participants would welcome P-1 and P-2 testing by independent laboratories, e.g., NREL. Several of the participants criticized using P-2 testing because it does not result in failures that can be correlated as well with those encountered from in service use. Furthermore, some industries use non-standard equipment for their testing. The size of specimens (14 in. x 20 in.) used in E 773-97 is thought by some to be no longer relevant because windows are now much larger. In addition, many manufacturers know how to make specimens that pass the test but that have little relevance to the durability of their products when deployed in the field. Also, passing the E 774-97 Specification at the CB level is not adequate for securing a durability of 20 years. The "harmonized North American standards" (Appendix 4) will not be as severe a test as the test in the current E 773-97 Standard (P-2). Insulating glass units that passed the Canadian standard typically had service lifetimes of 5 years. Analysis of some real time tests by U.S. manufacturers requires destruction of the unit to measure the amount of desiccant consumed. For real time testing, non-destructive, non-invasive measurements, e.g., optical or "dewpointer" measurements are needed for evaluating the IGU performance. The "dewpointer" is a commercially available unit for measuring the temperature at which condensation can be observed in an IGU.

SIGMA has assembled the results of a 20-year field study using units certified by the ASTM tests and even the highest grade IGUs that passed E 774-97 at the most-demanding CBA level have a 4% failure rate. A current industry need is to devise new testing protocols that can be used to evaluate the durability. By identifying the mechanisms of degradation, evaluating the real-time degradation of field-deployed IGUs, and using an optimum accelerated testing protocol, service lifetime predictions for IGUs can be made by using the protocol described [2,3]. NFRC has not directly addressed the durability of IGU seals although the Long-Term Energy Performance Subcommittee is conducting a small project that will be completed in 2001. From the results, a testing protocol might be identified that could be useful for testing seal durability.

Recommendation: Fund NREL to develop new accelerated testing protocols for IGUs that more closely simulate reality, to purchase two chambers for evaluating the merits of P-1, P-2, and the newly devised protocols, and to consolidate the variations into one protocol.

Recommendation: Fund NREL and other independent laboratories with in-depth experience with IGU testing to assess the durability of IGUs, develop a plan for predicting service lifetimes, and implement the plan.

2(b). Are the (accelerated testing) procedures proprietary? **No.**

3. What are the options for field testing or lab testing to determine the degree of seal failure as inferred from argon fill level retained or moisture content increase?

All testing is done in laboratories. Except for using the "dewpointer" (cost is about $1000) or a simplified variant of it like the cold-puck test [4], no good non-destructive test exists for testing for the water vapor concentration inside the closed space of field deployed units. In the cold-puck test, a 1.5-in. diameter disc is held against the glass and the contacting surface is systematically varied from 0 to – 80°C. The dewpoint is typically measured to ±3°C.

The argon concentration may be inferred from the oxygen content measured with an oxygen analyzer. However, a more direct measurement involves using Raman spectroscopy [5], which measures the oxygen and nitrogen content directly, but no portable unit exists and no plans are in place to develop one. Infrared thermography, which has been partially developed at LBNL [6], is a possible technique for argon determination based on the temperature of glass under standard conditions. Using design suggestions from the PPG laboratory and a doctoral thesis by a U. of Nova Scotia candidate, H. Elmahdy has developed a prototype high voltage discharge argon and krypton determination apparatus that was demonstrated at the SIGMA meeting on August 14, 2000. Henry Taylor of Architechural Testing Inc. is developing a method for measuring the thermal conductance inside an IGU. The status of Taylor's development needs to be determined.

The Canadian CGSB 12.8 standard currently includes requirements for determining the initial argon fill level, conditioning the unit to established conditions, and determining the final argon fill level. Testing for the IGMAC Certification Program began in Canada in June 1998. ASTM, the Insulating Glass Coordinating Council (IGCC), and SIGMA are currently reviewing the CGSB 12.8 procedure for inclusion as a certification requirement in the U.S.

Recommendation. Evaluate the benefit of energy saved versus cost to the consumer when using argon instead of air in an IGU.

Recommendation. Fund the *deployment* of a portable spectrometer or suitable variants, e.g., the Elmahdy device, for the non-destructive, non-invasive determination of the concentration of argon or krypton in field- or laboratory tested IGUs. Alternatively, fund (perhaps through the SBIR program) the *development* of a different type of portable spectrometer or suitable variants, e.g., one that is based on spectroscopic analysis such as used by Cardinal IG. A unit is needed to monitor the percentage of inert gas fill for production lines.

4(a). Is argon out-diffusion accompanied by in-diffusion of moisture as well as air?

Refer to page 17 of Appendix 2. The concave configuration shown for the two glass panes is called "glass collapse" or "dishing" by those in industry. I prefer dishing because the changes in shape are reversible. Dishing can also occur because of temperature changes. When sealed at the factory, a fixed number of molecules are trapped in the internal volume of the IGU. The pressure inside the unit obeys the ideal gas law, i.e., $P = nRT/V$ or $K'T$ in which K' is nR/V, so the pressure is proportional to the absolute temperature. Because IGUs are assembled at room temperature in factories close to sea level, a new unit will form concave dishing when outdoor temperatures are below room temperature and convex dishing when the outdoor temperatures are above room temperature. At high elevations, the lower pressures as well as the temperature excursions will increase the extent of dishing. Because IGUs with EC coatings will operate at greater temperature extremes, e.g., -30°C to +90°C, than contemporary low E IGUs, the potential problems from dishing will likely be increased.

The driving force for out-diffusion of argon and in-diffusion of air is the concentration gradient resulting from using pure argon in the IGU closed space and air outside the IGU. As given in pages 14—16, Appendix 2, argon diffusion is faster through most sealant materials than nitrogen and oxygen, so the result is a net loss of molecules in the closed space of the IGU. The concomitant decrease in internal pressure in the IGU results in the concave dishing shown on page 17, Appendix 2. PIB is the only sealant commonly used with negligible differences in permeation rates among argon, nitrogen, and oxygen. Hence, PIB is used as the primary seal by nearly every manufacturer, but different manufacturers use different secondary seals. Nearly all manufacturers use a dual seal system (Appendix 7, page 5). If skipping in the primary seal takes place during fabrication [question 1(a)], the choice of the secondary seal material greatly affects the lifetime of the IGU. When applying the PIB seal, skipping in the corners of the IGU is especially difficult to avoid. The reduced pressure in the IGU may be a safety issue.

No concentration gradient would exist if the IGUs were filled with air. The net energy benefit is minor [question 6], so using air is a reasonable technological solution. Unfortunately, argon has been marketed as an energy saver instead of for better reasons for using it, e.g., the living space is more comfortable because the inside glass temperature is warmer (Appendix 7, pp. 13-15).

Recommendation. Obtain the water permeation rates for commonly used seal materials.

4(b). Has moisture in-diffusion been measured or only inferred from dew point measurements?

It is inferred from dew point measurements that are accurate to about ±3°C. During the diffusion processes described [question 4(a)], the actual rate of in-diffusion of water vapor is difficult to measure non-destructively because of the action of the desiccant [question 5(a)].

4(c). If not measured, are there plans to measure moisture directly in the inside space of IGUs?

Water vapor concentration is measured with a dewpointer or estimated with the cold-puck method [4]. Both measurements are non-invasive and non-destructive. Because of the low cost, convenience of use, and portability of the dewpointer, a spectroscopic method for water vapor determination is not a special need by industry. However, an alternative to the dewpointer or cold-puck methods for measuring water vapor would be helpful.

4(d). Are any low E coatings attacked by moisture or by liquid water when condensation occurs?

No known hard coats, e.g., indium tin oxide and SnO_2 are affected by condensation. Soft-coat low E (silver) coatings may be corroded because water vapor is present or contaminated by lubricating oils. The presumed mechanism is that water vapor transports reactants such as chlorides or sulfides to the silver surface from other parts of the IGU. The chlorides and sulfides may be present because of improper rinsing during fabrication. Pure silver is not oxidized by water vapor or air at the temperatures and pressures of IGUs, even at the temperatures used in the tests described [question 2], or at the temperatures anticipated for EC coatings in IGUs. Silver has less than a monolayer of oxygen adsorbed on the surface when exposed to air at room temperature; however, the adsorbed oxygen can be replaced with a chloride or sulfide [7]. A protective barrier layer could be introduced on top of the silver to protect it from any reactions. M. Rubin at LBNL was cited as a probable source of the changes in optical properties because of reactions with silver surfaces.

4(e). Which ones or what combinations? See the response to question 4 (d).

5(a). Is a desiccant essential for keeping the moisture content in an IGU low?

Yes. Except for specialty products such as evacuated units, all IGUs must contain a desiccant to maintain a dew point below –40°C.

5(b). Do all (contemporary) IGU units made contain a desiccant?

Yes. IGUs were made in the 1960s with fused or soldered seals that did not need a desiccant but these are no longer on the market.

5(c). How long (estimated years) is the desiccant effective?

This depends on many factors including the kind of desiccant chosen, amount of desiccant, the quality of the seal, the choice of sealant materials, and the "loading" of the desiccant when introduced into the unit. Some desiccants are exposed to humid air for many hours before they are placed in the unit during manufacturing. Because desiccants are inexpensive, most manufacturers over-engineer the amount of desiccant used so it does not become the limiting factor for the more than 20-year service life expected for IGUs.

6(a). What does a seal failure mean in terms of energy conservation?

The intent of this question is "what is the change in U-factor (formerly known as U-value) if pure argon is replaced with air." From a broad perspective, the major reductions in U-factor from ~1.1 to ~0.25 and the corresponding energy savings have resulted from introducing double pane windows and low E coatings. These and other gains are illustrated for different window types (Appendix 7, pp. 10-11, Appendix 8, Figure A-2 [8], and Appendix 9 [9]). With the most expensive construction and design, i.e., triple pane, two low E coatings, and with krypton gas fills, the U-factor can be reduced to about 0.13 or so, but the major energy savings result from using double pane, low E, and an air fill (Appendix 7, pp. 10-11, and 16-17). Perhaps, the reason why most IGUs sold since 1993 have a U-factor ranging from 0.35 to 0.55 and the median U-factor of 0.45 in 1999 has not changed significantly since 1994 (0.47, Appendix 10 [9]) is because cost conscious consumers consider the tradeoff between energy and product cost. A number of illustrations on the calculated energy performance of different types of windows in a "standard" building are also available (Appendix 8, [8]).

6(b). What is the difference in U-factor for 99% argon versus pure air when the U-factor is 0.24 for 99% argon?

As given in 6(a), the change is only from 0.24 up to about 0.28 or 0.29 Btu/h-ft_2-°F.

7. Have the increases in U-factor for the change in different initial gaps (resulting from up to complete replacement of argon with air and the resulting decrease in the internal IGU pressure) been compared with those is question 6?

No, but some information may be gained by studying the ASHRAE article by M. Bernier in [10]. The effect of changes in the gap from dishing may also be calculated with a program called glass_pt that is available through W. Lichtenberger [11].

Recommendation: Use a computer model to evaluate the effect of gap collapse on the increase in U-factors from temperature-induced pressure changes as well as those resulting from the pressure decrease because of the net loss in molecules present inside the IGU from the more rapid out diffusion of argon.

8(a). Do you know of publications or reports that can help me with the above questions?

Most respondents were not able to provide bibliographic information. Glass Digest was cited as a source of articles, but with the warning that the authors write the articles with a bias in contrast with the expectations of those who publish articles in refereed technical journals.

8(b). If so, can you provide me with copies or the reference citations?

References that were provided are included in the Reference citation list or are attached in one of the Appendices.

9. Would DOE development of an inexpensive portable gas monitor for field testing the argon fill in IGUs be helpful?

Answers ranged from it would be enormously helpful to the consumer and unhelpful for industry, except for use on a production line, to it is not needed because of the minor effect argon has on saving energy. Elmahdy has developed a prototype high voltage discharge argon determination apparatus that was demonstrated at the SIGMA meeting on August 14, 2000. He has also demonstrated the usefulness of the device for detecting other gases such as krypton. Industry should be encouraged to develop an argon monitor for production lines. In addition, it is recommended that DOE provide support for improving, producing, and making Elmahdy's device available for use.

10. The remaining comments/questions are directly from (Bob Spindler's) SIGMA presentation; if you need a fax of the relevant pages, please let me know as soon as possible. I do not have an electronic file of the SIGMA visuals (Appendix 2) that Bob Spindler used for the SIGMA presentation (Appendix 2 was received from R. Spindler after all the Emails had been sent and most phone conversations completed).

This item was only for information.

11. SIGMA viewgraphs, pp. 3, 4, 10, and 11; Vacuum filled units receive better fills than Lance filled units. Is the widespread use of Lance filling just a matter of cutting production costs?

The statement is true. Lance filling is used for certain designs and for cutting production costs. During fabrication, a wide variance exists on how long to flush to obtain the desired argon fill.

12. SIGMA viewgraphs, p. 27; (a) What are the units on the winter U-factor that ranges from 0.24 to 0.27 for argon fills from 100% to 50%?

The units are in Btu/h-ft^2°F.

12(b). Do you have a summary of the U-factor for various types of windows ranging from single pane through triple pane and double low E?

No. This information is partly available in Reference 8 and can be deduced from the annual NFRC Directory of Fenestration Products [9]. Selected examples are shown in Appendices 7, 8, and 9. Additional relevant information is given in Appendix 11.

13. SIGMA viewgraph, p. 30; the problem seems to be solved. (a) Why should DOE want to enter the fray?

Although at least one firm is convinced that 20-year service lifetimes are routinely achievable, not all firms have the same commitment to correct materials selection, challenging accelerated life testing, and quality control during manufacture. Legal action such as the one given in Appendix 3 can discourage consumers from taking advantage of the energy savings available when ***any*** IGUs are used. Thus, energy that could be saved may not be saved because of a consumer reluctance to install ***any*** IGUs in buildings.

13(b). Is it because of low-cost fabricators that do not have a commitment to quality and durability?

IGU seal durability ***does*** depend strongly on quality control during manufacturing. Some companies "cut-corners" to be competitive or enhance their profit margins. The result can be a product with less than 20 years of service life with a concomitant frustration of the consumer.

13(c). What can DOE do that has not already been done or is being done by industry?

DOE has moved too slowly with the Energy Star program and the fenestration heating (FHR) and fenestration cooling (FCR) ratings through NFRC. They could help by getting building codes changed.

Recommendations. DOE should consider (i) funding work to consolidate all the variations in accelerated and real time testing into one protocol and turn it into a new ASTM standard, (ii) carrying out a survey of installed units in the field and determine how well they are functioning, (iii) support for a comprehensive project to obtain service lifetime predictions of IGUs, (iv) leading aggressively for developing standards and having them adopted ASTM many years before a developing technology is ready for the consumer, e.g., the type of leadership that has been in progress since 1995 for preparing standards about chromogenic glazings, (v) producing simplified documentation for the consumer on "how to select an energy efficient window for your home, what to look for in a warranty, how to calculate the energy saved/cost tradeoffs, and how to maintain an IGU (Ref. 8, which is an excellent overview about IGUs, is much too detailed for the average consumer), (vi) supporting R&D to create a new class of IGU, (vii) funding a scholarly person or persons to work with selected individuals in industry to prepare papers and reports from the vast knowledge available about IGUs and publish the documents in peer-reviewed journals, e.g., convert R. Spindler's paper (Appendix 2) into an ASHRAE paper, and (viii) evaluating the merits of suggestions made by industry (Appendix 2, p. 34).

Site Visit. After considering the content of this initial report that was completed in August 2000, Dr. Taylor asked the author to visit Aspen Research Corporation. A copy of the trip report prepared by the author and E. Tracy of NREL is attached as Appendix 12.

IGU Standards Activities and Key Contacts. The organizations that are preparing standards, have an interest in using the standards, are active in testing of IGUs are listed in Table 2. Key organizational contacts are also listed in Table 2.

Acknowledgements

The author is deeply grateful to the participants for their generous contributions of their time, talent, and knowledge that, in a few cases, has spanned up to nearly 40 years during the development of IG units. The author also thanks R. Spindler for providing Appendix 2, the NFRC for providing the copy used in Appendix 3, J. Haberer and the ASTM task group E06.22.05 for developing the documents in Appendix 4, W. Lichtenberger for providing Appendices 5 and 6, W. Lingnell for providing Appendix 7, the NFRC as sources of Appendices 8-11, and J. Fairman and his colleagues for providing the materials in Appendix 12. J. Zwart is also thanked for providing the draft copies of the prEN1279 series referenced in Table 1. The author led the Electrochromic Window R and D Task at NREL prior to his retirement in December 1999 and has been NREL's representative at ASTM and NFRC meetings since 1993.

Table 2. Organizations Engaging in IGU Standards Activities, Testing IGUs, or with an Interest in Using the Standards and Key Contacts.

Organization	Principal Interest	Key Contact Person(s)
AAMA	Specifier of IGUs	Carl Wagus
ASTM Task Group E02.22.05	Sealed Insulating Glass	Jeff Haberer
ASTM Task Group E02.22.02	Fenestration Durability	Dave Kehrli
ASTM Task Group E02.22.07	Durability of Chromogenic Glazings	Al Czanderna
ASTM Subcommittee E02.22	Durability Performance	Dave Kehrli
*IGMA	Insulating Glass Units	Bill Lingnell
ISO TC 160	IGU Durability	Bill Lingnell, Jeff Haberer
CEN	Glass in Buildings	Werner Lichtenberger
IEA Task 27	Electrochromic Window Durability	Mike Rubin, G. Jorgensen*
Aspen Research Corp.	IGU Testing Laboratory**	Jim Fairman
Cardinal IG	IGU Testing Laboratory**	Bob Spindler
ETC Laboratories	IGU Testing Laboratory**	Dave Kehrli

Organizational Contact Data

Contact Person	Email Address	Phone Number	Fax Number
Czanderna, Al	czanalv@attglobal.net	(303) 986 1234	(303) 986 1234
Fairman, Jim	jfairman@aspenresearch.com	(651) 264 6262	(651) 264 6270
Haberer, Jeff	Jhaberer@cardinalcorp.com	(612) 929 3134	(612) 929 7229
Kehrli, Dave	dave@etclabs.com	(716) 328 7668	(716) 328 7777
Jorgensen, Gary***	gary_jorgensen@nrel.gov	(303) 384 6113	(303) 384 6342
Lingnell, Bill	lingnell@swbell.net	(972) 771 1600	(972) 771 1600
Lichtenberger, Werner	lichtenberger@truseal.com	(905) 522 9058	(905) 522 4160
Rubin, Mike	mdrubin@lbl.gov	(510) 486 7124	(510) 486 6099
Spindler, Bob	Rspindler@cardinalcorp.com	(612) 929 3134	(612) 929 7229
Wagus, Carl	crwagus@aamanet.org	(847) 303 5664	(847) 303 5774

* Insulating Glass Manufacturing Alliance (IGMA) was formed in the fall of 2000 by combining the two associations known as IGMAC and SIGMA

** Other industrial testing laboratories exist, and these two are mentioned because the principal contacts contributed to this report and are known to provide testing services to other IGU manufacturers

*** Contact data will be useful if NREL is funded to participate in the durability testing activities needed for the IEA Task 27 group.

References

1. W. Lichtenberger, "Field Performance of Insulating Glass," presented at the Windows Innovation Conference—1995. (Reprinted as Appendix 6).

2. H-M. Kim, G. J. Jorgensen, D. E. King, and A. W. Czanderna, in R. J. Herling, ed., *Durability Testing of Nonmetallic Materials,* ASTM STP 1294, American Society for Testing and Materials, Philadelphia, PA, 1996, pp. 171-189.

3. A. W. Czanderna, D. K. Benson, G. J. Jorgensen, J-G. Zhang, C. E. Tracy, and S. K. Deb, *Solar Energy Materials and Solar Cells,* **56** (1999) pp. 419-436.

4. The cold-puck test is used extensively in Europe for estimating the dew point in an IGU. A 1.5" diameter cylindrically shaped disc that is immersed in dry ice and held against one of the IGU glass surfaces. Any formation of a condensate is detected visually.

5. A. C. R. Pipino, *Applied Spectroscopy*, **44** (1990) pp. 1163—1169.

6. C. Kohler, Prospects for Field Measurements of Insulated Glazing Durability Using Transient Thermal Tests, M.S. thesis, Eindhoven U. of Technology, The Netherlands (Work done at LBNL and a copy of the thesis may be obtained from the author).

7. A. W. Czanderna, *J. Phys. Chem.,* **68** (1964) 2765.

8. J. Carmody, S. Selkowitz, and L. Heschong, *Residential Windows, A Guide to New Technologies and Energy Performance,* W. W. Norton & Co., New York, 1996.

9. Certified Products Directory, Energy Performance Ratings for Windows, Doors, and Skylights, Ninth Edition—December 1999, National Fenestration Rating Council, Silver Spring, MD. Selected pages copied to illustrate the small differences in U-factor between air and argon-filled double-glazed windows.

10. M. Bernier, ASHRAE Transactions: Research, **103** (1997) pp. 270-277.

11. W. Lichtenberger, private communication, August 2000. Glass_pt is a simple program prepared by A. Dalgliesh (Structures Laboratory, Institute for Research in Construction National Research Council of Canada) for calculating the pressure dependence of the deflection at various temperature combinations.

Appendices to the IGU Seal Durability Report

Appendix 1 **An Example of Emails sent to the Participants Prior to Holding Telephone Conversations.**

Appendix 2 **Copy of Viewgraphs Used in a Presentation at the Sigma Argon Technical Session on February 2, 1999 Provided by Robert Spindler of Cardinal IG.**

Appendix 3 **Copy of Settlement Offer about Hurd Gas-filled Windows or Doors.**

Appendix 4 **List of Relevant ASTM Standards, Copies of ASTM E 773-97 and ASTM E 774-97 Standards about IG Units, and Copies of Proposed ASTM Standards, which are Intended to Harmonize the Differences between the Canadian Standard CAN/CGSB 12.8 and ASTM E 773-97 and ASTM E 774-97 Standards about IG Units, i.e., E-XXX, Standard Test Method for Insulating Glass Unit Performance; E-YYY, Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units; and E-ZZZ, Standard Specification for Insulating Glass Unit Performance and Evaluation.**

Appendix 5 **Copies of the 1970s versions of proposed P-1, P-2, and P-3 ASTM standards, three CEN documents about solar energy incident on vertical wall directed to the south and the calculation of the amount of UV that reaches the sealant in an IGU, and a memo in which the UV amounts are compared when the P-1 and P-2 testing protocols are used.**

Appendix 6 **Copy of a Paper Entitled "Field Performance of Insulating Glass," by Werner Lichtenberger that was Presented at the Windows Innovation Conference—1995 and Provided by W. Lichtenberger.**

Appendix 7 **Copy of a SIGMA Technical Report, TR-1401-96 Entitled "Insulating Glass Unit U-Values," Provided by William Lingnell of Lingnell Consulting.**

Appendix 8 **Copies of Selected Pages from Reference 8 About the Effect of Different Window Constructions on the U-Factor, Other Properties, and Annual Energy Performance.**

Appendix 9 **Copies of Selected Pages from Reference 9 About the Effect of Argon or Air Gas Fills on the U-Factor of Representative Equivalent Window Units.**

Appendix 10 **Copies of Selected Pages from Reference 9 About the Installation of IGUs as a Function of Time and the U-Factor of Installed Window Units Beginning in 1993.**

Appendix 11 **NFRC 100 Combined: Procedures for Determining Fenestration Product U-Factors.**

Appendix 12 **Summary of Trip Report from a Site Visit on November 15, 2000 at Aspen Research Corporation, White Bear, Lake, MN and Attachments about Aspen Research that were Supplied by the Hosts.**

Appendix 1

An Example of Emails sent to the Participants Prior to Holding Telephone Conversations

Dear Jim (Fairman), (July 29, 2000)

I have been asked by Ren Anderson and Gary Jorgensen of NREL, who are acting on behalf of Sam Taylor at DOE, to prepare a summary of the technical issues and recommendations related to IGU seal durability, and especially as they relate to advanced windows. I will greatly appreciate your help because of your work and knowledge about IGUs. To facilitate our discussion, I have prepared a series of questions and comments that have come to my mind, and will be pleased if you add others to the list that I have not thought about. We can bypass those that may be outside your personal domain of expertise. As my starting point, I have studied a copy of the viewgraphs used by Bob Spindler of Cardinal IG for his presentation to the Sealed Insulating Glass Manufacturers Association (SIGMA) in February 1999 and notes taken by Ren and Gary in a meeting with Bob Spindler, Ben Hurn, Bernie Herron, and Jim Fairman on December 13, 1999. The questions and comments are copied below.

I will call you during the week of July 31 to obtain your input. If the time when I call is not convenient for you, I would appreciate being able to schedule a time when we could talk.

Sincerely yours,

Al Czanderna, Consultant to NREL

Questions and Comments About Seal Durability in IGUs

1. (a) What is the current understanding of degradation mechanisms of seals? (b) Are the causes of ruptured seals, bond loss, and permeation failures known? (c) Are there any other failure modes? (d) Are failures always, usually, or rarely catastrophic?
2. (a) What are the accelerated testing procedures used to project lifetimes of seals? (b) Are the procedures proprietary?
3. What are the options for field testing or lab testing to determine the degree of seal failure as inferred from argon fill level retained or moisture content increase?
4. (a) Is argon out-diffusion accompanied by in-diffusion of moisture as well as air? (b) Has moisture in-diffusion been measured or only inferred from dew point measurements? (c) If not measured, are there plans to measure moisture directly in the inside space of IGUs? (d) Are any low E coatings attacked by moisture or by liquid water when condensation occurs? (e) Which ones or what combinations?
5. (a) Is a desiccant essential for keeping the moisture content in an IGU low? (b) Do all IGU units made contain a desiccant? (c) How long (estimated years) is the desiccant effective?
6. (a) What does a seal failure mean in terms of energy conservation? (b) What is the difference in U-factor for 99% argon versus pure air when the U-factor is 0.24 (units?) for 99% argon?

7. Have the losses in U-factor for the change in different initial gaps (resulting from up to complete replacement of argon with air and the resulting decrease in the internal IGU pressure) been compared with those is question 6?
8. Do you know of publications or reports that can help me with the above questions? If so, can you provide me with copies or the reference citations?
9. Would DOE development of an inexpensive portable gas monitor for field testing the argon fill in IGUs be helpful?
10. The remaining comments/questions are directly from (Bob Spindler's) SIGMA presentation; if you need a fax of the relevant pages, please let me know as soon as possible. I do not have an electronic file of the SIGMA powerpoint visuals that Bob Spindler used.
11. SIGMA viewgraphs, p. 6; Vacuum filled units receive better fills than Lance filled units. Is the widespread use of L filling just a matter of cutting production costs?
12. SIGMA viewgraphs, p. 14; (a) What are the units on the winter U-factor that ranges from 0.24 to 0.27 for argon fills from 100% to 50%? (b) Do you have a summary of the U-factor for various types of windows ranging from single pane through triple pane and double low E?
13. SIGMA viewgraph, p. 15; the problem seems to be solved. (a) Why should DOE want to enter the fray? (b) Is it because of low-cost fabricators that do not have a commitment to quality and durability? (c) What can DOE do that has not already been done or is being done by industry?

Appendix 2

Copy of Viewgraphs Used in a Presentation at the Sigma Argon Technical Session on February 2, 1999 Provided by Robert Spindler of Cardinal IG.

Appendix 3

Copy of Settlement Offer about Hurd Gas-filled Windows or Doors

Appendix 4

List of Relevant ASTM Standards, Copies of ASTM E 773-97 and ASTM E 774-97 Standards about IG Units, and Copies of Proposed ASTM Standards Intended to Harmonize the Differences Between Canadian and ASTM Standards

List of ASTM Standards Relevant to IG Units

E 546-88(1999)e1 Standard Test Method for Frost Point of Sealed Insulating Glass Units

E 546-88(1999)e1 Standard Test Method for Frost Point of Sealed Insulating Glass Units in the Vertical Position

E 773-97 Standard Test Method for Accelerated Weathering of Sealed Insulating Glass Units

E 774-97 Standard Specification for the Classification of the Durability of Sealed Insulating Glass Units

E 1887-97 Standard Test Method for Fog Determination

Copies of E-773-97, E-774-97, and of Each of Three Proposed ASTM Standards, which are Intended to Harmonize the Differences Between the Canadian Standard CAN/CGSB 12.8 and ASTM E 773-97 and ASTM E 774-97 Standards about IG Units, i.e.

E-XXX, Standard Test Method for Insulating Glass Unit Performance

E-YYY, Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units

E-ZZZ, Standard Specification for Insulating Glass Unit Performance and Evaluation.

Appendix 5

Important Historical Documents about P-1, P-2, and P-3 Testing and the Amount of UV Exposure Received by the Sealant Material

1. **Publication by PPG entitled "ASTM Test Methods for Insulating Glass" which includes**
   a. **ASTM E6 P3, Proposed Specification for Sealed Insulating Glass Units,**
   b. **ASTM E6 P1, Proposed Recommended Practices for Testing Seal Longevity of Sealed Insulating Glass Units, and**
   c. **ASTM E5 P2, Proposed Recommended Practices for Testing Seal Durability of Sealed Insulating Glass Units.**

2. **CEN Document entitled "Annex 2: Estimation of the Solar Energy (Incident) on Vertical Walls Directed South."**

3. **CEN Report by Glass Control B entitled "An Experimental Study of the UV Radiation Exposure of the Edge Seal of the Glazed Insulating Glass Unit."**

4. **CEN Telefax Report by Frank Simonis of TNO Institute of Applied Physics, Eindhoven, The Netherlands to Mr. Bernard Lowe containing a calculation of the amount of UV that reaches the IG sealant. The author of the handwritten English translation is unknown**

5. **A memo to a colleague from W. Lichtenberger about the UV exposure in test methods used at Truseal Technologies. The memo is based on a conversation with J. Spetz (J. Spetz Consulting, Wickliffe, OH), who did not respond to a copy that was sent to him about the conversation.**

Appendix 6

Copy of a Paper Entitled “Field Performance of Insulating Glass,” by Werner Lichtenberger That was Presented at the Windows Innovation Conference—1995 That was Provided by W. Lichtenberger

Appendix 7

Copy of a SIGMA Technical Report, TR-1401-96 Entitled "Insulating Glass Unit U-Values," provided by William Lingnell of Lingnell Consulting.

Appendix 8

Copies of Selected Pages from Reference 8 About the Effect of Different Window Constructions on the U-Factor, Other Properties, and Annual Energy Performance

Appendix 9

Copies of Selected Pages from Reference 9 About the Effect of Argon or Air Gas Fills on the U-Factor of Representative Equivalent Window Units

Appendix 10

Copies of Selected Pages from Reference 9 About the Installation of IGUs as a Function of Time and the U-Factor of the Installed Window Units Beginning in 1993

Appendix 11

NFRC 100 Combined: Procedures for Determining Fenestration Product U-Factors

Appendix 12

Summary of Trip Report from a Site Visit on November 15, 2000 at Aspen Research Corporation, White Bear Lake, MN and Attachments about Aspen Research that were Supplied by the Hosts.